Asymmetric Dark Matter in Supersymmetry

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Introduction

We know that asymmetric dark matter can solve the coincidence problem:

$$\Omega_{Dark\ Matter} \simeq 5\,\Omega_{Barionic\ Matter}$$

Can we have asymmetric dark matter in supersymmetry?

Proposed mechanism

T_{High}: Lepton asymmetry generated (assumed that is possible)

$\Downarrow$

$m_{SUSY} < T < T_{seesaw}$: Asymmetry is redistributed among particles in chemical equilibrium

$\Downarrow$

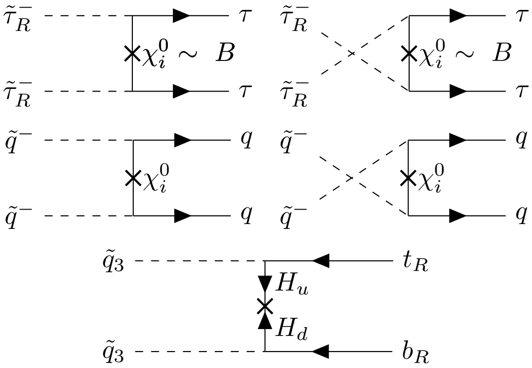
$T \sim m_{SUSY}$: Sparticles annihilation and/or decay to the Next Lightest Supersymmetric Particle (NLSP), in this case the $\tilde{\tau}_R$

$\Downarrow$

$T \sim m_{NLSP}$: NLSP annihilation. Before Big Bang Nucleosynthesis (BBN)
$\tilde{\tau}_R \to \tau + \psi_\mu$, ψ_μ gravitino

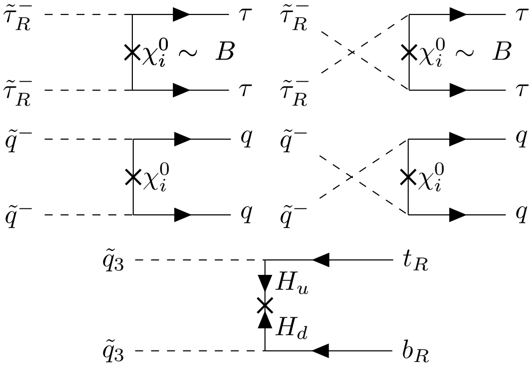
Proposed mechanism

Processes that can wash-out the sparticle asymmetry



Proposed mechanism

Processes that can wash-out the sparticle asymmetry



Must be supressed!!

↓

Small μ and Dirac Bino enough?

Problems with the model

Lets find when the $\tilde{\tau}$ annihilation freezes out

$$H = \frac{1.66 g_*^{1/2} T^2}{m_{Pl}} \simeq \frac{17 m_{\tilde{\tau}_R}^2}{z^2 m_{Pl}} \lesssim n_{\tilde{\tau}_R}^{eq} \begin{cases} \sigma(\tilde{\tau}_R + \tilde{\tau}_R \to \tau\tau) v \\ \sigma(\tilde{\tau}_R + \bar{\tilde{\tau}}_R \to f f) v \end{cases} \quad , \quad z = \frac{m_{\tilde{\tau}_R}}{T}$$

then the freeze out

$$\Gamma(\tilde{\tau}_R + \tilde{\tau}_R \to \tau\tau) \sim \frac{\tilde{m}^3}{z^{3/2}\pi^2} e^{-z} \sigma(z) \approx \frac{10 m_{\tilde{\tau}}^2}{z^2 m_{Pl}}$$

so

$$\sigma(z) < \frac{1.66\sqrt{g_*}\,(2\pi)^{3/2}}{m_{Pl}\, m_{\tilde{\tau}_R}} \frac{e^z}{\sqrt{z}} \simeq 2.2 \cdot 10^{-20} \frac{e^z}{\sqrt{z}} \left(\frac{m_{\tilde{\tau}_R}}{1000 \text{ GeV}}\right) \text{ GeV}^{-2}$$

$$\sigma(5) < 4.9 \cdot 10^{-19} \left(\frac{m_{\tilde{\tau}_R}}{1000 \text{ GeV}}\right) \text{ GeV}^{-2}$$

$$\sigma(10) < 5.2 \cdot 10^{-17} \left(\frac{m_{\tilde{\tau}_R}}{1000 \text{ GeV}}\right) \text{ GeV}^{-2}$$

Problems with the model

On the other hand

$$\sigma(\tilde{\tau}_R + \tilde{\tau}_R \to \tau\tau) \sim \frac{4\pi\alpha^2 M_M^2}{M_D^4}$$

Majorana masses at tree level for Wino and Gluino, at loop level for Bino but

$$10^1 \text{ GeV} < M_B < 10^2 \text{ GeV}, \; M_{DB} \sim 10^3 \text{ GeV} \longrightarrow \sigma \sim 10^{-5} \text{ GeV}^{-2} \longrightarrow z \sim 34$$

Gauginos masses contribution still too big!

$\Downarrow$

Then we need Dirac Gauginos

Dirac Gauginos

Also the top-bottom process has cross section

$$\sigma(\tilde{q}_3\tilde{q}_3 \to t_R b_R) \sim \frac{(Y_b Y_t)^2}{8\pi M_h^2} \times \left(\frac{\mu}{M_h}\right)^2$$

Freeze out temperature

$$e^{-z_{\tilde{q}_3}}\sqrt{z_{\tilde{q}_3}} \lesssim \frac{128\pi}{(Y_b Y_t)^2}\frac{M_h^2}{M_{Pl} m_{\tilde{q}_3}}\left(\frac{M_h}{\mu}\right)^2, \quad z_{\tilde{q}_3} = \frac{m_{\tilde{q}_3}}{T}$$

Satisfied for $\mu \sim 0.1 - 1$ TeV, $z_{\tilde{q}_3} \sim 20$

Too much washing out!

$\downarrow$

We need R-symmetry

Almost R-symmetric models

We need Dirac Gauginos + Dirac masses for Higgsinos ⇒ softly broken R-symmetric model

- If exact R-symmetry ⇒ asymmetry is related to the primordial R-charge and we lose the connection with the lepton asymmetry.

The whole process happens in a R-symmetrically except for the NLSP decay.

Dirac Gauginos

To obtain Dirac masses for the gauginos, we must introduce additional states in adjoint representations of the different gauge groups:

• $S \equiv$ hypercharge singlet • $T_i \equiv$ weak triplet • $O_i \equiv$ color octet

Superpotential

$$W = Y_u\, u\, q\, H_u - Y_d\, d\, q\, H_d - Y_e\, e\, l\, H_d + \mu_D\, R_d\, H_d + \mu_U\, R_u\, H_u +$$
$$+ \lambda_{SD}\, S\, R_d\, H_d + \lambda_{SU}\, S\, R_u\, H_u + \lambda_{TD}\, R_d\, T\, H_d + \lambda_{TU}\, R_u\, T\, H_u + M_{S_1 S_2} S_1\, S_2$$
$$+ \kappa\, S_1^3 + \longleftarrow \text{ R-violating term}$$
$$+ \lambda_1\; H_u\, H_d\, S_1 + \longleftarrow \text{ Ensures equal chemical potentials for Higgsinos}$$

Almost R-symmetric models

Then we get

$$\frac{Y_{\tilde{\tau}}}{Y_B} = \frac{3818}{23329} \simeq \frac{1}{6}$$

Lead to gravitino mass

$$m = 30 \text{ GeV}$$

It works!

Let's see a working point

Sample point

Parameters

- $m_{SUSY} \sim 2$ TeV
- $\tan\beta \sim 15$
- $\lambda_{SD,SU,TU} \sim -0.1$
- $\lambda_{TD} \sim 0.1$
- Dirac masses ~ 3 TeV
- $\kappa \sim 10^{-3}$

Particles masses

- Higgs ~ 122 GeV
- $\tilde{\tau} \sim 1.69$ TeV
- Lightest neutralino ~ 1.77 TeV

Summary and Further Discussion

What we have found

- It is possible to have asymmetric dark matter in SUSY and solve the coincidence problem.
- We need a softly broken R-symmetric model with gravitino dark matter.
- We get a relatively light stau and a prediction for the dark matter mass of 30 GeV.

What can be improved

- Can it work for other spaticles as NLSP?
- Can it work for neutralino dark matter?

Thank you!

Leptogenesis and coincidence problem

Leptogenesis

- Bariogenesis: Sakharov conditions
  - Barion number violation
  - CP violation
  - Out of equilibrium decays
- Leptogenesis: asymmetry generated in leptons passes to barions via sphalerons
- Coincidence problem

$$\Omega_{Dark\ Matter} \simeq 5\ \Omega_{Barionic\ Matter} \quad !!$$

Supersymmetry

- Symmetry between bosons and fermions $\longrightarrow$ Superpartners!
- Dirac or Majorana gauginos?

Reheating temperature

We look for the bound on the reheat temperature T_R to ensure $\Omega_{3/2} \ll \Omega_{DM}$

$$Y_{3/2} m_{3/2} \simeq 1.5 \times 10^{-8} \frac{100\text{GeV}}{m^{3/2}} \left(\frac{m_{SUSY}}{10\text{TeV}}\right)^2 \frac{T_R}{10^8\text{GeV}}$$

and with $\Omega_{DM}/\Omega_B \sim 5$ and $Y_{\Delta B} \simeq 8.75 \times 10^{-11}$

$$T_R \lesssim 10^6 \text{ GeV}$$

So at $t_R \sim 10^6$ GeV we make asymmetry in $B/3 - L_{\tilde{\tau}}$

Dirac Gauginos

To obtain Dirac masses for the gauginos, we must introduce additional states in adjoint representations of the different gauge groups:

- $S \equiv$ hypercharge singlet
- $T_i \equiv$ weak triplet
- $O_i \equiv$ color octet

Dirac gaugino masses are then generated by a hidden sector $U(1)'$ spurion that gets a D-term though an operator,

$$\int d^2\theta \, \sqrt{2} \, \frac{W'_\alpha W_j^\alpha}{M} \, \Phi_j \, , \tag{1}$$

with W' and W_j the hidden sector and visible sector gauge superfields respectively and Φ_j the new chiral superfield in the adjoint representation.

Dirac Gauginos superpotential

$$
\begin{aligned}
W_{DG} = & Y_u \; u \; q \; H_u - Y_d \; d \; q \; H_d - Y_e \; e \; l \; H_d + \mu H_u H_d + \\
& + \lambda \; S \; H_d \; H_u + 2\lambda_T H_d T H_u + \\
& + L_1 \; S + \frac{M_S}{2} S^2 + \frac{\kappa}{3} S^3 + M_T \mathrm{Tr}(TT) + M_O \mathrm{Tr}(OO) + \\
& + \lambda_{ST} S \mathrm{Tr}(TT) + \lambda_{SO} S \mathrm{Tr}(OO) + \frac{\kappa_O}{3} \mathrm{Tr}(OOO)
\end{aligned} \quad (2)
$$

with soft terms

$$
-\Delta \mathcal{L}^{soft} = -\Delta \mathcal{L}^{scalarsoft}_{MSSM} - \Delta \mathcal{L}^{scalarsoft}_{adjoints}
$$

Dirac Gauginos superpotential

where

$$-\Delta\mathcal{L}^{scalarsoft}_{MSSM} = [T_u\ u\ q\ H_u - T_e\ e\ l\ H_d + h.c.] +$$
$$+ m^2_{H_u}|H_u|^2 + m^2_{H_d} + [B_\mu H_u H_d + h.c.] +$$
$$+ q^i (m^2_q)^j_i q_j + u^i (m^2_u)^j_i u_j + d^i (m^2_d)^j_i d_j + l^i (m^2_l)^j_i l_j + e^i (m^2_e)^j_i e_j$$
$$-\Delta\mathcal{L}^{scalarsoft}_{adjoints} = (t_S S + h.c.) +$$
$$+ m^2_S |S|^2 + \frac{1}{2} B_{M_S}(S^2 + h.c.) + 2m^2_T \mathrm{Tr}(T^\dagger T) + (B_T \mathrm{Tr}(TT) + h.c.) +$$
$$+ \left[A_\lambda \lambda S H_u H_d + 2A_T \lambda_T H_d T H_u + \frac{1}{3}\kappa A_\kappa S^3 + h.c.\right] +$$
$$+ 2m^2_O \mathrm{Tr}(O^\dagger O) + (B_O \mathrm{Tr}(OO) + h.c.)$$

Spontaneous symmetry breaking

Issues with spontaneously R-symmetry breaking

- We need to fine tune the model to break the symmetry late enough.
- We would have a massless goldstone boson